GIAP Journals

International Journal of Students' Research In Technology & Management
Vol 4 (1) Jan-Feb 2016, pg 08-11
eISSN 2321-2543, doi: 10.18510/ijsrtm.2016.413

Design and Development of Vibration Testing Fixtures

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***Abstract*— this paper deals with the Design of Vibration Testing Fixtures for Random Vibration loads as specified by the MIL 810 military standards. Following selection of the right material and configuration of the fixtures, CAD models are generated and numerically checked for natural frequencies and mode shapes using Finite Element Analysis. Based on these results, the response of the fixtures to the MIL 810 standard Random Vibration profile input is measured using Finite Element Analysis and the transmissibility is calculated. Finally, the fixture is tested experimentally for to the MIL 810 standard Random Vibration profile input and based on these values; transmissibility of the fixture is computed. The experimental result is compared to the Finite Element results and thus, found that the fixture can be used for testing missile packages at the Defense Research and Development Laboratory (DRDL), Hyderabad.**

I. Introduction

Testing of a component for any kind of vibrations involves mounting it on a shaker with the help of an intermediate element called a Fixture. A vibration testing fixture interfaces the package to be tested with the source of vibration. A good fixture must have its natural frequencies lying beyond the operational range of the test frequencies and must possess a transmissibility of 1. Figure 1 shows the schematic representation of the process of vibration testing. It was required to design fixtures for a random vibration load of 0.01 g2/Hz over a frequency range of 50-200 Hz as per the MIL 810 standard for testing against transportation loads.

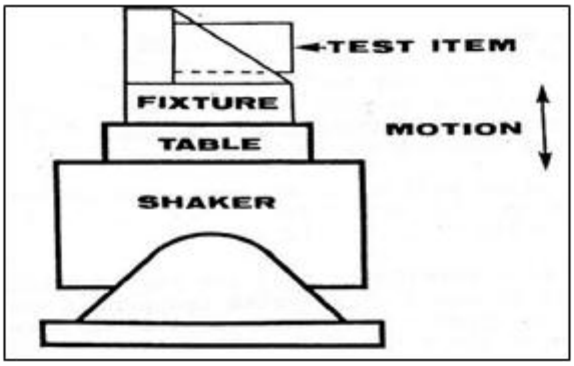

Figure 1

The dimensions of the fixture are usually chosen based on the component to be tested and the size of the shaker (source of vibration). In this particular case dimensions were arbitrarily chosen based on the shaker table diameter of 400 mm. Although many configurations of fixture can be used, the L and T configurations were selected as they offer high stiffness, strength to weight ratio and ease of fabrication. The material for the fixtures was chosen as Aluminum alloy LM 25 as it is a known fact that aluminum and magnesium offer better strength, stiffness, vibration damping properties compared to steel compared to steel fixtures of same geometry and weight. However, fabrication of magnesium fixtures is not feasible from the consideration of casting and welding Hence Easily available aluminum alloy LM 25 is chosen.

II. Design Procedure

The CAD models of the fixtures were generated using Solid works. The dimensions of the fixtures are shown in Fig: Subsequently modal analysis was performed on the fixtures using a Finite Element Analysis package called FeMAP (developed by Siemens with an integrated Nastran solver). The 10 noded tetrahedral element was used to mesh the geometry. The first five natural frequencies of the L and T fixtures were identified and corresponding mode shapes were determined. They are shown in the table below.

Table 1: First Five Natural Frequencies of L and T Fixtures Obtained from FEA

S.No.	Natural frequencies of L fixture (Hz)	Natural frequencies of T fixture (Hz)
1	900.93	1369.77
2	1043.40	1372.36
3	2038.92	1765.90
4	2061.20	2386.65
5	3102.82	2580.00

It was observed that the natural frequencies of the fixtures were well beyond the test frequency range of 20-500 Hz. Using the mode shapes, the points with maximum amplitude of vibration were determined.

Consequently, the random response of the fixtures in X, Y and Z directions to an input of 0.01 $g^{2/}$Hz in X, Y and Z directions (individually) was computed using FeMAP. The gRMS values of the response PSD was compared to the input PSD was measured and plotted as graphs with using MATLAB, with Frequency (20-2000 Hz) on the X axis and the response

PSD (in $g2^{/}$Hz) on the Y axis. Transmissibility is computed as

$$Q = \sqrt{\frac{Input\ gRMS(Area\ under\ the\ output\ curve)}{Output\ gRMS(Area\ under\ the\ input\ curve)}}$$

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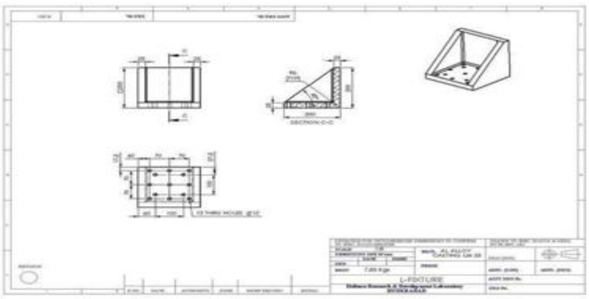
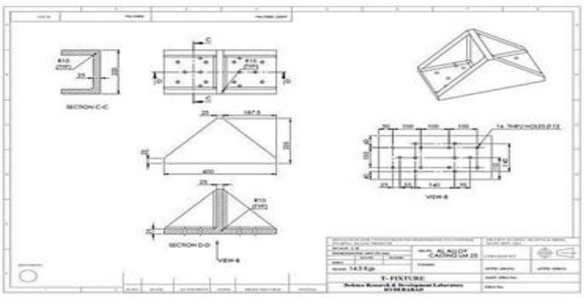
It was observed that the output response in X direction was in close agreement with in X direction up to the frequency range of 500 Hz, while the Y and Z responses to input in X direction were negligible. The same was observed when input was given in Y and Z directions. The table below shows the gRMS values of responses in various directions to input in X, Y and Z directions obtained using FeMAP. The transmissibility was obtained as 1. This indicates theoretically that the performance of the fixtures under transportation loads is satisfactory.

III. FABRICATION PROCEDURE OF THE VIBRATION FIXTURES

As the Finite Element Analysis predicted that the transmissibility of the fixture works satisfactorily under transportation loads, the same was to be experimentally verified. For this the fixture was fabricated. The fabrication process began with selection of the Aluminum alloy LM 25 for realizing the fixtures. Aluminum is suitable for the given problem since it simulates the real time conditions of the test component. In addition to having good vibration damping properties, aluminum has better (E/ρ) ratio compared to steel and is easier to fabricate compared to magnesium. The 3D cad models the two types of vibration fixtures were created using Solid works. The manufacturability and feasibility studies were carried out.

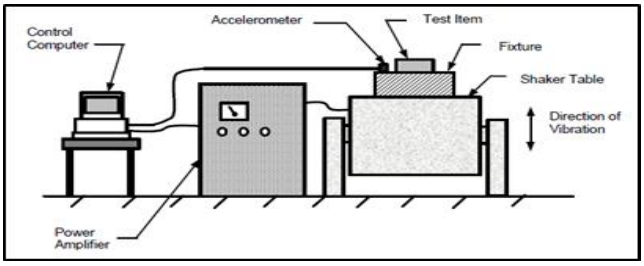
Patterns were prepared according to the geometries of the L and T fixtures with provision for machining allowance and moulds were prepared from them. Molten aluminum was poured into the moulds and was allowed to solidify and cool for 48 hours. Following solidification the riser and the gates were removed. Following the casting procedure excessive material and blow holes were removed by milling operation using a cutter of diameter 12 mm. Fillets of radius 10 mm were made using a cutter of the same dimension Holes of diameter 12 mm were drilled on the bottom face of the fixtures as specified in the engineering drawings to accommodate bolts to secure the fixtures to the shaker table. The dimensions of the fixtures after machining were verified by measurement and were found to be in accordance with those mentioned in the drawings. The fully fabricated fixtures are shown below and the engineering drawing was extracted from the CAD.



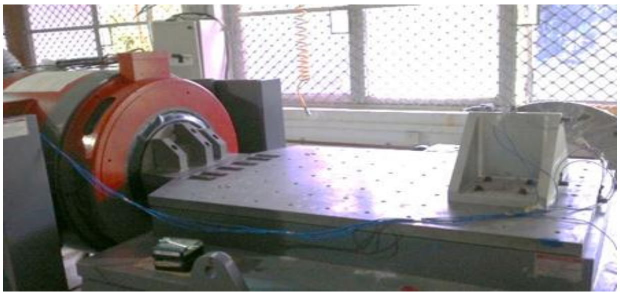


IV. TESTING OF FIXTURES

The fixtures designed were experimentally tested for their random response characteristics in a frequency range of 20-500 Hz, since missile subsystems are to be tested using the L and T type fixtures experience transportation loads in the same frequency range. The fixtures are mounted on an electromagnetic shaker table for the purpose of vibration testing. The shaker works on the principle of electromagnetic induction. The vibration imparted by the shaker to the fixtures can be controlled by controlling the current input to the shaker by means of the Data Acquisition. The schematic representation of the test setup is shown in the adjacent sketch.



Piezoelectric accelerometers (Model and make used: B&K 2635) were mounted on the critical locations of the fixtures where response was to be measured, and as well as on the shaker table. The accelerometers were connected to the Data Acquisition System (DAQ) (Model and make: LMS SCADA S III SPECIFICATIONS), which in turn was connected to the computer. This setup forms a closed loop control system and enables the user to control the input to the shaker. An input of 0.01 g^2/Hz in the frequency range 20-500 Hz was given to both L and T fixtures, as per the MIL 810 standard for transportation load. The observations were recorded using **Lab view.** The response to input excitation in each direction (X, Y & Z-independently) was recorded in all three directions. The pictures below show the fixtures mounted on the shaker with the accelerometers placed on them.



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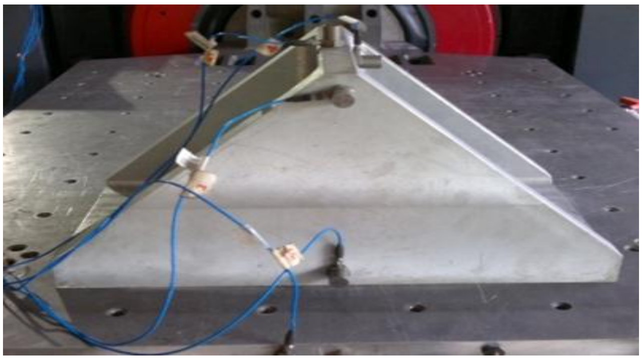

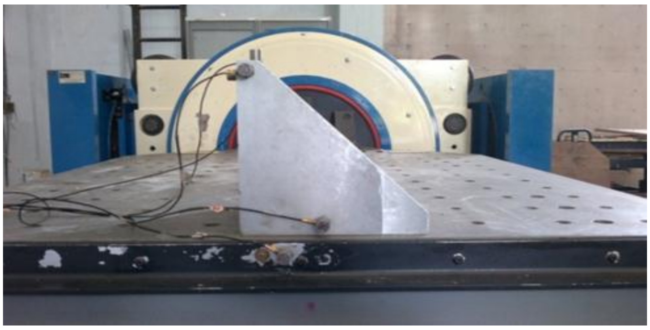

V. Observations and Results

The gRMS values of the response spectrum was computed from the results obtained from the experiment and the data was plotted in the form of a graph using MATLAB, with Frequency (20-500 Hz) on the X axis and the response PSD (in g2/Hz) on the Y axis.

It was observed that the output response in X direction was in close agreement with in X direction, while the Y and Z responses to input in X direction were negligible. The same was observed when input was given in Y and Z directions. The table below shows the experimentally obtained gRMS values of responses in various directions to input in X, Y and Z directions.

Table 2

Excitation & Response Direction	Response achieved in gRMS
L Fixture	
X excitation Input=2.1908 gRMS	
x response	2.4637
y response	0.0189
z response	0.0156
Y Excitation Input=2.1908 gRMS	
x response	0.4032
y response	2.5128
z response	0.0493
Z excitation Input=2.1908 gRMS	
x response	0.0046
y response	0.0407
z response	2.2076
T Fixture	
X excitation Input=2.1908 gRMS	
x response	2.3319
y response	0.1012
z response	0.0142
Y Excitation Input=2.1908 gRMS	
x response	0.0072
y response	2.3095
z response	0.0058
Z excitation Input=2.1908 gRMS	
x response	0.0667
y response	0.0231
z response	2.2076

VI. Conclusions

By comparing the gRMS values of the output obtained by the Finite Element Analysis with the experimental output as seen in the table below, it is evident that they are in close agreement up to a frequency range of 500 Hz, thus giving the value of transmissibility of the fixtures as 1. Very minor deviation in the response curves is observed. They are because of the assumptions made during the Finite Element Analysis such as isotropic behavior of the material, difference between modeling of constraints of bolts and holes and real time conditions. Additional mass and stiffness effects of the fasteners are also not considered in the analysis. All these factors may cumulatively affect the analytical results after a range of 500 Hz

Table 3: Comparison of Experimental and Theoretical Responses of Fixtures to Input PSD

L Fixture	Input=2.1908 gRMS for X, Y and Z excitations			
X Excitation	FEA response (gRMS)	Transmissibility	TEST response (gRMS)	Transmissibility
x response	2.2145	1.01≈1	2.4637	1.12≈1
y response	0.2939	-	0.0189	-
z response	0.0097	-	0.0156	-
Y Excitation	FEA response (gRMS)		TEST response (gRMS)	
x response	0.3917	-	0.4032	-
y response	2.2063	1.007≈1	2.5128	1.014≈1
z response	0.3917	-	0.0493	
Z Excitation	FEA response (gRMS)		TEST response (gRMS)	
x response	00.0906	-	0.0046	-
y response	0.4686	-	0.0407	-
z response	2.0683	0.988≈1	2.2076	1.007≈1
T Fixture	Input=2.1908 gRMS for X, Y and Z excitations			
X Excitation	FEA response (gRMS)		TEST response (gRMS)	
x response	2.2120	1.009≈1	2.3319	1.064≈1
y response	0.2633	-	0.1012	-
z response	0.1191	-	0.0142	-

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VII. Future Scope

As an extension of this project, work the following aspects can be covered. By incorporating few changes in the fixture design such as increasing the stiffness based on the mode shapes the fixtures can be used to test missile subsystems up to frequency of 2000Hz. Different configurations of fixtures such as box fixtures, conical and assembled fixtures can be designed for the same purpose and their responses to the same input can be verified analytically and experimentally. Further, by using damping treatments like rubber and elastomers, the amplification at resonance can be controlled making the fixtures effective even at resonance. Damping studies, weight optimization and fatigue life estimation of the fixtures can be carried out.

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